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Analysis Method of Errors (Motion and Atmospheric) in Synthetic Aperture Radar (SAR) Images

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Abstract. A method to allow the analysis of the effects of motion and atmospheric errors in SAR images is here presented. The objective of the method is to allow the visualization of the effects of motion errors and atmospheric artefacts on the processed (focused) SAR image. The method is intended to allow the analysis of the interaction of motion and atmospheric errors with the adopted SAR processing procedure and motion compensation algorithms. In this article the analysis method has been applied and tested to a C-Band E-SAR (DLR airborne SAR system) data set where we see that the effects of linear and non-linear phase errors observed are in agreement with the theory.

1 Introduction

High resolution images, polarimetric data, repeat-pass Interferometry are specially affected by motion and atmospheric errors. Moreover, phase effects can limit the interpretation of repeat-pass interferometric SAR applications like Differential Interferometry (D-InSAR) in the way that subsidence of terrain or crustial deformation may be biased either by an atmospheric phase screen or by residual motion errors (Ferretti et al., 2003; Danklmayer et al., 2004; Macedo and Scheiber, 2004; Scheiber, 2003; Prats, 2004).

Generally speaking the effects of the motion and atmospheric errors in the SAR image are the same, differing mainly in intensity and distribution along the image. Motion errors are associated to the flight instability around the nominal track (Macedo and Scheiber, 2004), while atmospheric effects are associated with erroneous propagation of the signal through the atmosphere (Ferretti et al., 2003). An atmospheric model applied to a SAR image geometry and acquisition characteristics is yet to be considered in a further work. One of the objectives of this paper is, once a model for atmospheric error is available, to use this model in the analysis method here proposed to see how the atmospheric effects take place (distribution and intensity) in the SAR image. Another objective of the proposed method is to permit the analyses of the interaction of the motion and atmospheric error with the processed algorithm used and error compensation algorithms. Below, we describe the nature of the motion and atmospheric errors.

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Motion Errors

The SAR raw data are processed assuming that the acquisition has been performed in a rectilinear trajectory. In reality the acquisition happens in a non-rectilinear track causing undesired phase delays in the acquired data (Fig. 1a) leading to distortions (phase offset, time shift and defocusing) of the Impulse Response Function (IRF) of the SAR processor (Buckreuß, S., 1994, 1991). The delay or phase error is 2π times the round-trip distance difference in wavelength, that is:

$$\phi_d = 4\pi \Delta R / \lambda \,, \tag{1}$$

where λ is the wavelength of radar signal and ΔR denotes the difference between nominal and real range.

Concerning flight stability, the airborne data are more affected by motion errors then the spaceborne data, and special care has to be taken during the processing chain to compute and compensate those errors (Scheiber, 2003; Prats, 2003; Moreira and Huang, 1994; Reigber and Scheiber, 2003). For actual airborne SAR systems, the motions errors vary up to 5 m around the nominal track.

Atmospheric Errors

Like the motion errors, the atmospheric errors will also cause phase errors due to the additional phase delay caused by the fact that the traveling path of the radar signal will be different for different atmospheric conditions (Fig. 1b). The reason can be found in the lower atmosphere (troposphere) for airborne SAR systems as well as due to additional ionospheric driven influences in spaceborne SAR systems. Amongst many errors, atmospheric errors are one of the last obstacles in the way to get high precision data at any arbitrarily chosen acquisition time. The background of this

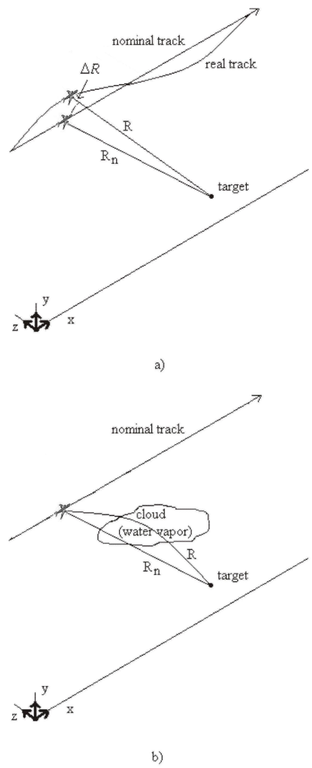

Fig. 1. Sketch showing the nature of the phase errors.

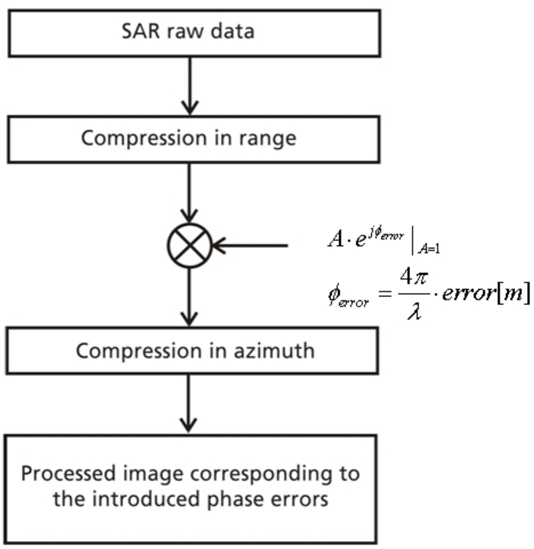

Fig. 2. Flow chart for the analysis procedure.

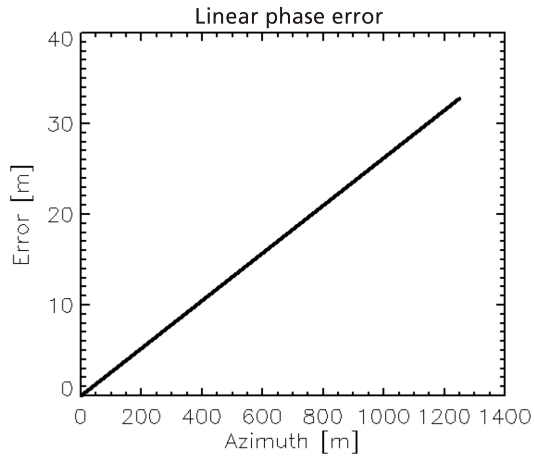

Fig. 3. Depiction of the linear phase error.

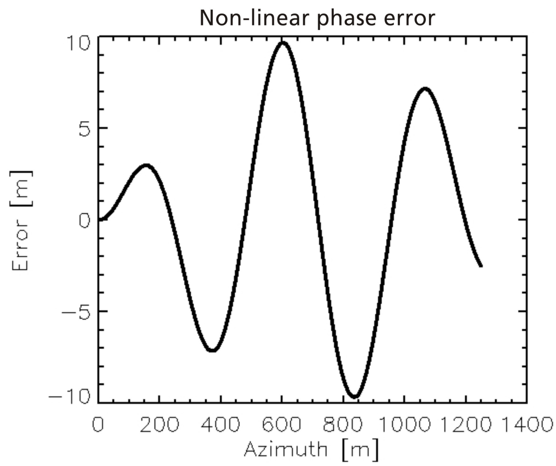

Fig. 4. Depiction of the non-linear phase error.

investigation can be considered in the context of future commercial SAR systems like TerraSAR-X (Werninghaus et al., 2004) and airborne SAR systems where control of product quality becomes increasingly important. Investigations on atmospheric effects in airborne SAR systems have not been found in the literature so far. For end users it is of great interest and importance to provide an indication of product quality and how likely products are affected by atmospheric artefacts.

At first instance it would be sufficient to flag such data using tropospheric partameters i.e. temperature, pressure, atmospheric humidity, wind speed, precipitation rate and in a following step one can concentrate to cancel such errors after the definite identification and localization. Of course this provides a challenging task.

This article is organized as follows: Sect. 2, describes the analysis method here proposed for motion and atmospheric errors. Section 3 shows the results of the use of the method for a known linear and non-linear phase error. The conclusions are given in Sect. 4.

2 Analysis Method

The analysis method can be best described using the flow chart which is provided in Fig. 2.

It consists of adding a phase error that corresponds to the effects of motion or atmospheric artefacts. This phase error

Table 1. Main parameter for the simulation.

Parameter	Value
Wavelength	0.0566 m
PRF	952.38 Hz
Flight velocity	72.6 m/s
Sampling frequency	100 MHz
Bandwidth	50 MHz
r0	1410 m
Azimuth pixel spacing	0.076 m
Range pixel spacing	3 m
Azimuth Dimension	16384 px / 1249 m
Range Dimension	512 px / 1536 m

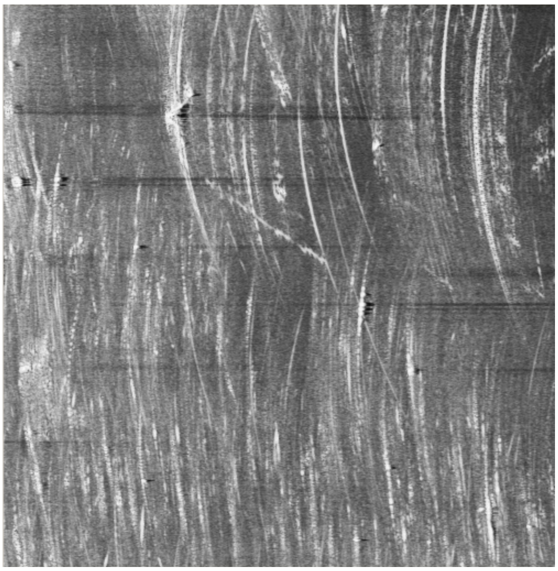

Fig. 5. Raw data after range compression.

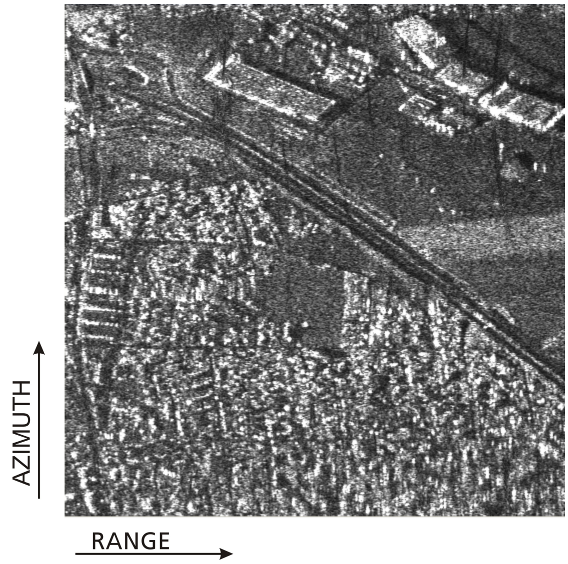

Fig. 6. Processed image with unmodified raw data.

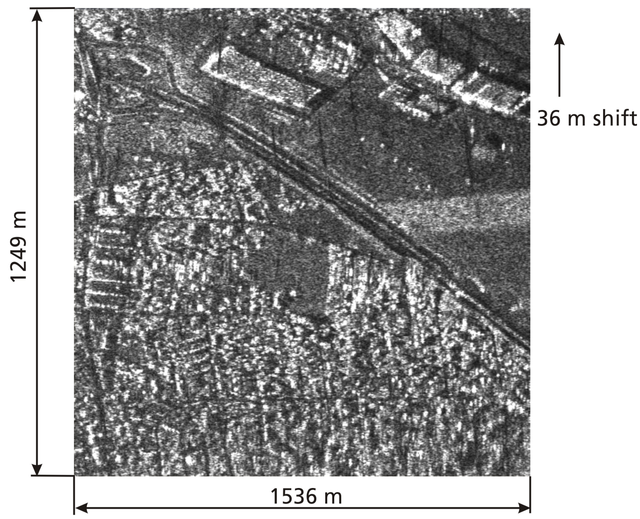

Fig. 7. Processed image with linear phase error.

is added to the raw data, before SAR data compression. Alternatively, the error can be added to the range compressed data since the phase error effects in azimuth are dominant (Scheiber, 2003; Prats, 2004).

The above analysis by adding the phase error to the raw data is only corrected for phase errros associated with motion errors along a flat terrain area. For topography-dependent phase errors, each target in the image has a different phase error (Macedo and Scheiber, 2005). In order to add and analyse topography-dependent phase errors, the FFT approach to compensate motion errors described in Macedo and Scheiber (2005) can be used to add (instead of compensating) phase errors.

In this work, the Range Doppler processor was used to compress the data. After the compression in range (see range compressed raw data in range in Fig. 4), the phase value errors have been added in order to see the effects of them in the processed SAR data. Up to now only linear and non-linear azimuth phase value errors have been considered (see Figs. 3 and 4) and the amplitude values of the added signals remained the same. The effects of this linear and non-linear phase errors are well known in the literature (phase offset, shift in time, defocusing), (Buckreuß, 1994, 1991). By using them we want to see these known effects in the SAR image by using the proposed analyses method and see if it is in agreement with the theory.

3 Results

The data to be analysed was collected in strip-map mode with E-SAR, the experimental SAR system which belongs to DLR, German Aerospace Center, operated by the Microwaves and Radar Institute (HR). Table 1 shows the main parameters of the used data.

In Fig. 4 we see the image which has been obtained after the two dimensional Range-Doppler compression without

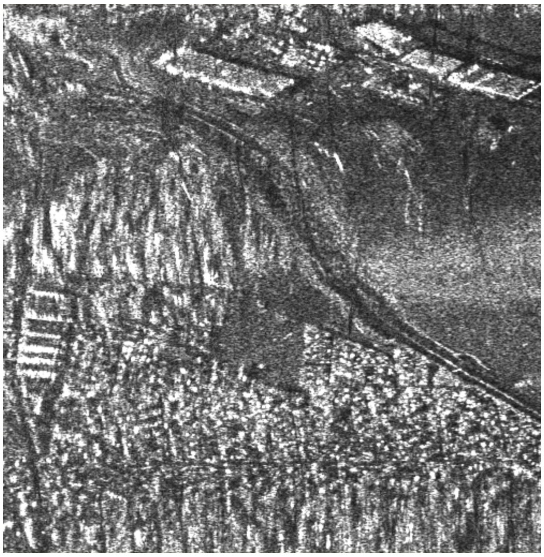

Fig. 8. Processed image with non-linear phase error.

introduction of additional phase values. Moreover in Figs. 5 and 6 the data with the linear and the nonlinear azimuth phase errors are given. The simulation for the linear case exhibits a vertical shift of the image of approximately 36 m. The calculation of this value can be done by using the following expression (Buckreuß, 1994, 1991):

$$S = -r_0 \frac{\partial \Delta r}{\partial x} \tag{2}$$

where S denotes the shift in meters, r_0 is the range distance and Δr is the phase error function.

In the case where the non-linear error was introduced to the raw data we observe basically two expected effects. One is in principle the same as in the linear case, to wit the shift in azimuth direction. The artificially bended road shown in Fig. 8 cf. Fig. 6 is an indicator of this effect. On the other hand defocusing took place which can be seen in the upper left of Fig. 8. This is not surprising if we consider the results that we obtain in the case of simple point targets, where simulations have already been carried out (Buckreuß, 1994, 1991). The same effects appear on the IRF for point targets if linear or non-linear phase errors are introduced. The effects are the broadening of the main lobe, the shift of the main lobe and the elevation of the sidelobes. Using the proposed analysis method allows us to see and analyze the effects for the whole SAR image.

What has to be done in one of our next steps in the investigation of the influence of phase errors is to adjust the values, in which we alter the pre-compressed raw data, to a realistic scenario. In the case of motion errors there is no doubt that typically values of the error are plus/minus 5 to 10 m from the nominal path. In the atmospheric case we are not fully aware of the detailed structure of the errors to be introduced. Therefore we have to clarify this issue with the help of a model to obtain the propagation conditions from the type of the weather and henceforth a pattern which can help to prove the possible influence on the products and how they are affected.

4 Conclusions

The way in which the data was analyzed and modified with the introduced phase errors shows how they affect the image reconstruction and represents an appropriate approach to tackle the issue of errors due to track oscillations and atmospheric artefacts. It has been shown that the resulting behavior due to linear and non-linear phase errors are as expected and in agreement with the theory. Future work consists of elaborating the simulation to allow the computation of interferograms in terms of phase errors. Furthermore we consider the elaboration of the atmospheric model to fit the SAR image concerning phase and attenuation effects.

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